Original Article

Correction of pre-existing astigmatism by on-axis incision size modulation in manual small-incision cataract surgery

Ruchi Goel, Ruchita Sontakke, Shalin Shah, Vaibhav Nagpal, Sushil Kumar, Omeshwer Koli, Shweta Ojha, Swati Saini, Deepanjali Arya

Purpose: To study the effect of wound size modulation on pre-existing astigmatism by on-axis placement of incision in manual small-incision cataract surgery (MSICS). **Methods:** In this prospective interventional study conducted at a tertiary care centre, 40 eyes of 40 consecutive senile cataract patients with 1.00–3.00 D corneal astigmatism were enrolled for the study. MSICS by modified Blumenthal's technique was performed through 6.0, 6.5, and 7.0 mm on-axis incision in 1.0–1.49 D (group A), 1.50–1.99 D (group B), and 2.00–3.00 D (group C) astigmatism, respectively. Surgically induced astigmatism (SIA) was calculated by vector analysis and double angle plots (DAP) at 12 weeks postoperatively. **Results:** There were 22 males and 18 females with mean age of 58.12 ± 1.18 years. The mean SIA at 12 weeks was 0.85 ± 0.28 D in group A (17 eyes), 1.32 ± 0.65 D in group B (10 eyes), and 1.91 ± 0.69 D in group C (13 eyes). The overall median uncorrected visual acuity was 0.18 (IQR = 0 to 0.2). The mean astigmatism decreased from 1.95 ± 0.74 D to 1.04 + 0.57 D (P = 0.00) in superior incision and from 1.70 + 0.50 D to 0.92 ± 0.45 D (P = 0.00) in temporal incision group with central shift of centroid in all cases. **Conclusion:** The customization of on-axis external incision size can be used to manage pre-existing corneal astigmatism of less than 3.00 D using both temporal and superior incisions effectively.

Key words: Manual small-incision cataract surgery, on-axis incision, surgically induced astigmatism, wound modulation

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High astigmatism following cataract surgery can be a common cause of poor uncorrected visual acuity. It creates blurred images through a bigger circle of least confusion on the retina and can cause glare and monocular diplopia.[1] An estimated 15–29% of elderly patients undergoing cataract surgery have a pre-existing astigmatism of ≥1.5 D. With advancing age, a greater steepening of the horizontal corneal meridian induces an against-the-rule (ATR) astigmatic shift.[2] In manual small-incision cataract surgery (MSICS), the reported surgically induced astigmatism (SIA) ranges from 1.00 to 3.00 D.[3] The SIA depends on the location, shape, size, cauterization, presence of suture, type of suturing, suture material used, and healing of the surgical incision.[4,5]

The commonly used strategies to correct the pre-existing astigmatism by cataract surgery are on- axis incisions, limbal relaxing incisions, and toric intraocular lenses.[6] Although implantation of toric intraocular lens produces predictable outcomes, the cost limits its universal applicability in developing countries.[7] Capitalizing on the greater SIA produced by scleral incisions extending beyond the astigmatically neutral funnel, an on-axis placement of incision perpendicular to the steep meridian can be employed to neutralize the pre-existing astigmatism. The component parts of SIA are the flattening of the steep meridian, steepening 90° away and torque at 45°.[8] The straight scleral incision is reported to induce a greater SIA compared to frown and Chevron incision.[9,10]

This study was, therefore, undertaken to determine the effect of change in size of straight scleral incision placed on the steeper meridian in MSICS for correction of pre-existing astigmatism.

Methods

A prospective non-randomized interventional study was performed from July 2021 to February 2022 at a tertiary eye care center in New Delhi, India. An institutional ethics committee clearance was obtained (F.1/IEC/MAMC/82/10/2020/NO.174) and the trial was registered with the clinical trials registry of India (CTRI/2021/06/034080).

Forty eyes of 40 consecutive patients with senile cataracts grade 3 and above and preoperative corneal astigmatism ranging from 1 D to 3 D was included in the study.

A written informed consent was obtained from all the study participants. Any pre-existing ocular conditions likely to affect

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the visual outcome or cause irregular astigmatism such as keratoconus, corneal opacities, large pterygium with corneal encroachment, corneal dystrophy, corneal degeneration, complicated cataract, traumatic cataract, subluxated cataract, lens-induced glaucoma, pseudoexfoliation syndrome, or any known case of glaucoma were excluded from the study. The study was conducted in accordance with the tenets of the Declaration of Helsinki.

All the patients underwent a complete ocular examination. Visual acuity was assessed using Snellen charts and converted to Log MAR Scale. Anterior segment examination, cataract assessment, Goldmann applanation tonometry, and fundus examination were performed. The nucleus grade 3 represented 'yellow nucleus', grade 4 had 'red/brown nucleus', and grade 5 included hypermature/Morgagnian nucleus.[11]

Pre-operative workup

Keratometry was done using Scheimpflug device Sirius TopoTomographer (CSO, Firenze, Italy). The refractive equivalent power display [Fig. 1a, b, f, g] was used to derive the simulated keratometry values from 3.0-mm central cornea, the flatter meridian keratometry (K1), steeper corneal meridian (K2), axis of steep meridian (angle p), and corneal astigmatism (A) values were obtained [Fig. 1c, e, h, j]. Preoperative ATR and with the rule (WTR) astigmatism were defined as corneal astigmatism 90° ± 20° (minus cylinder form) and 180° ± 20° (minus cylinder form) based on preoperative keratometry readings.

Axial length was measured by optical method wherever possible, using LensStar 900 (HaagStreit diagnostics, Koeiniz, Switzerland) with a target refraction as emmetropia. In patients with advanced cataracts, an ultrasound biometry was done by an expert ophthalmologist using 10 MHz linear probe of PacScan 300 AP (Sonomed Escalon, NY, USA). The intra-ocular lens (IOL) power was calculated using Barret's Universal II Formula (https://calc.apacrs.org/barrett_universal2105/).

Surgical procedure

All the patients underwent MSICS using modified Blumenthal's technique with posterior chamber intraocular lens implantation (PCIOL) under peribulbar anaesthesia by a single experienced surgeon (Ruchi Goel).[12] Based on the pre-operative corneal astigmatism, 1.0–1.49 D, 1.50–1.99 D, and 2.00–3.00 D, the cases were divided into groups A, B, and C, respectively. The size of incision was kept as 6.0 mm in group A, 6.5 mm in group B, and 7.0 mm in group C. The axis of the steepest corneal meridian was taken as mid-point of the external incision and marked intra-operatively using Mendez Toric Marker.

After conjunctival peritomy, a straight external incision, 6.0, 6.5, or 7.0 mm with the pre-marked mid-point, was created 1.5 mm from the limbus. A triplanarsclero-corneal tunnel was dissected up to 2 mm into the cornea to make an internal opening of 8.00–9.00 mm. Two side ports were created, and the anterior chamber maintainer (ACM) was fixed temporally for superior incision, superiorly for temporal incision, and connected to a syringe containing 2% hydroxy propyl methyl cellulose. Capsulorrhexis was performed and nucleus was prolapsed into the anterior chamber following hydrodissection. The nucleus was delivered using visco pressure created through ACM and gentle intermittent depression of the posterior scleral lip, assisted by debulking of the presenting nucleus with a 26 G needle.

The cortex was washed under ACM flow and a rigid polymethyl methacrylate (PMMA) non-foldable PCIOL with a 6-mm optic size was implanted within the capsular bag. The side ports were hydrated, and the conjunctival flap was reposited over the main wound.

Postoperative care and follow-up

Patients were administered prednisolone 1% eye drops six times a day in the first postoperative week and gradually tapered every week during 6 weeks. Topical gatifloxacin (0.3%) four times a day for 4 weeks and tropicamide (0.5%) twice a day for 1 week were also administered. Keratometry, uncorrected, and best corrected visual acuity were recorded at 12 weeks postoperatively. The scleral flap thickness at the limbus was measured at 12 weeks using anterior segment optical coherence tomography (REVO 60N, Optopol Technology, Poland) [Fig. 1d and i].

SIA analysis

The SIA was calculated at 12 weeks using the standardized calculator by Dr. Hill (https://www.doctor-hill.com/physicians/sia_calculator.htm).

Vector analysis of the astigmatism changes was done using Cartesian coordinate geometry.[13] Preoperative and postoperative astigmatic data were used to generate X (horizontal) and Y (vertical) vectors. The amplitude of corneal astigmatism (A) was calculated from the difference in the keratometry values of steeper and flatter meridian. Using the trigonometry formulas for $x = A\cos 2p$ and $y = A\sin 2p$, where P is the axis of the steep meridian, we calculated X_{PRE}, X_{POST}, Y_{PRE}, and Y_{POST}. The amplitude of SIA was calculated for each eye as $X_{SIA} = X_{POST} - X_{PRE}$ and $Y_{SIA} = Y_{POST} - Y_{PRE}$. The SIA was calculated for each case in terms of magnitude and angle as follows[14]:

$$\text{SIA magnitude} = \sqrt{X_{SIA}^2 + Y_{SIA}^2}$$

$$\text{SIA angle} = 0.5 \times \arctan\left(\frac{Y_{SIA}}{X_{SIA}}\right)$$

The centroid was defined as the arithmetic mean of all the astigmatism vectors under consideration. It was calculated individually for each group and subgroup, preoperatively and postoperatively. The keratometry was used to calculate the corneal astigmatism. The X_{PRE}, Y_{PRE}, and axis were used to plot each case preoperatively on the double angle plot (DAP). The arithmetic means of all X_{PRE} and Y_{PRE} values were taken as $\bar{X}_{PRE}$ and $\bar{Y}_{PRE}$, respectively. The magnitude and angle of the centroid were calculated as follows:

$$\text{Preoperative centroid magnitude} = \sqrt{\bar{X}_{PRE}^2 + \bar{Y}_{PRE}^2}$$

$$\text{Preoperative centroid angle} = 0.5 \times \arctan\left(\frac{\bar{Y}_{PRE}}{\bar{X}_{PRE}}\right)$$

The postoperative centroid values were calculated in a similar way using X_{POST} and Y_{POST} values for each case. All centroid values were represented as positive cylindrical power in diopters.

DAP was designed for accurate and quantitative representation of the astigmatism changes with multiple concentric rings, each

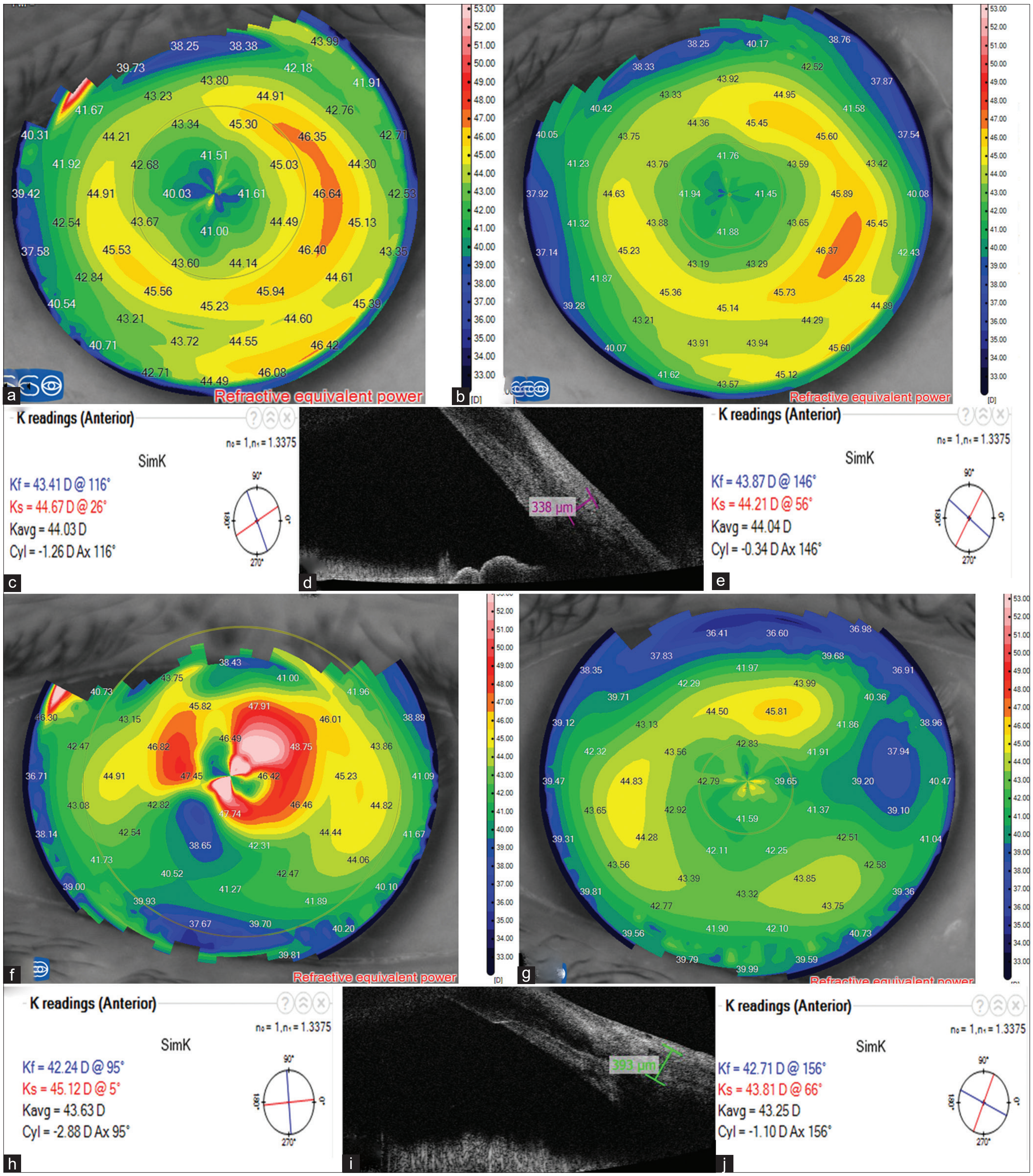

Figure 1: Representative case in group A (a–e) Corneal topography expressed as refractive equivalent power (a) pre-operative (b) 12 weeks post-surgery, (c) preoperative keratometry values showing astigmatism of 1.26 D @ 116°, (d) anterior segment Optical coherence tomography (OCT) image showing 338 microns depth at limbus (e) keratometry 12 weeks post-surgery showing residual astigmatism 0.34 D @ 146°. Representative case in group C (**f–j**): Corneal topography expressed as refractive equivalent power (f) Pre-operative (g) 12 weeks post-surgery (h) preoperative keratometry values showing astigmatism of 2.88 D @ 95° (i) anterior segment OCT image showing 393 microns depth at limbus (j) Keratometry 12 weeks post-surgery showing residual astigmatism 1.10 D @ 156°

representing 1 D.[14] The individual keratometry values were represented as empty circle and the centroid as solid circle. The axis of astigmatism was plotted on the chart after doubling the angle. The 12′o clock position represented 45° and thus, the supero-temporal cornea. The 3'o clock and 9'o clock positions represented the temporal and superior incision sites.

Statistical analysis

The data were analysed using version 24 of Statistical Package for Social Science software (SPSS v. 24.0). The normality of the data was assessed using Kolmogorov–Smirnov test. The quantitative data were presented as mean ± standard deviation (SD). Any data with a skewed distribution were expressed as median (interquartile range – IQR). The difference between preoperative and postoperative keratometry and astigmatism was tested using paired *t*-test. The ANOVA test was used to study the difference between SIA induced in group A, B, and C. The Mann–Whitney Test was used to compare the SIA of superior versus temporal incision. P value < 0.05 was considered as statistically significant.

Results

In the 40 study participants, 22 were males and 18 were females with ages ranging from 40 to 80 years and the mean age being 58.12 ± 1.18 years. There were 21 left (52.5%) and 19 right (47.5%) eyes. There were 17 eyes in group A, 10 in group B, and 13 in group C. Twelve, six, and seven eyes had nucleus grade 3 in group A, B, and C, respectively. Nucleus grade 4 was present in four eyes of group A and in four eyes of group B. One eye in group A and two eyes in group C had grade 5 nucleus. The three groups were gender and age-matched. Thirteen eyes had pre-existing WTR astigmatism and 27 eyes had ATR astigmatism.

The mean LogMAR best corrected visual acuity of the affected eye at presentation was 1.09 ± 0.28, which improved to 0.03 ± 0.08 (P = 0.00) at 12 weeks. The median Uncorrected visual acuity (UCVA) at 12 weeks post-surgery was 0.18 (IQR = 0 to 0.2). The mean scleral flap thickness measured at 12 weeks by OCT was 316.00 ± 35.75 microns.

The mean astigmatism decreased from 1.78 ± 0.59 D at presentation to 0.96 ± 0.50 D (P = 0.001) and the median (IQR) of X_{SIA} and Y_{SIA} were –0.35 (–0.95 to 0.58) D and 0.27 (–0.57 to 0.71), respectively, at 12 weeks.

The mean SIA at 12 weeks in group A was 0.85 ± 0.28 D, in group B was 1.32 ± 0.65 D, and in group C was 1.91 ± 0.69 D. The post-hoc analysis showed significant differences in the mean SIA between the groups A and B (P = 0.05), groups A and C (P = 0.00), and groups B and C (P = 0.02). The mean X_{SIA} at 12 weeks was –0.05 D in group A, –0.14 D in group B, and –0.71 D in group C. The mean Y_{SIA} at 12 weeks was 0.08 D, 0.13 D, and 0.14 D in groups A, B, and C, respectively. The intergroup comparison of changes in mean X_{SIA} and Y_{SIA} were statistically insignificant.

The mean astigmatism decreased significantly in both superior and temporal incision groups at 12 weeks. In the superior incision group, astigmatism changed from 1.95 ± 0.74 D to 1.04 ± 0.57 D (P = 0.00) and in the temporal incision group from 1.70 ± 0.50 D to 0.92 ± 0.45 D (P = 0.00). Although the overall SIA was greater in the superior incision as compared to the temporal incision group, the difference was statistically insignificant (P = 0.386). The mean X_{SIA} was 0.98 ± 0.56 D in the superior incision and –0.89 ± 0.86 D in temporal incision (P = 0.00). The mean Y_{SIA} in the superior incision was 0.50 ± 1.16 D and in the temporal incision was –0.08 ± 0.75 D (P = 0.08).

The DAP plots showed displacement of the centroid from the periphery towards the center in all the three groups [Fig. 2]. The centroid changed from 0.96 D @ 99° to 0.38 D @ 104° and 1.09 D @ 8° to 0.56 D @ 13° in group A with superior and temporal incision, respectively. Group B showed a change of centroid from 1.33 D @ 93° to 1.03 D @ 121° and 1.63 D @ 170° to 0.69 D @ 7° in superior and temporal incision groups, respectively. The centroid shifted from 2.62 D @ 91° to 1.26 D @ 95° and 2.18 D @ 180° to 0.56 D @ 176° in groups C with superior and temporal incision, respectively. A central shift of centroid with clustering of individual cases towards the centre was observed in all groups.

Discussion

The SIA in MSICS can be titrated by altering the size, shape, depth, location, and distance from limbus of the external incision, wound closure, suturing technique, and dose of postoperative steroids.[9] The placement of surgical incision on the steeper corneal meridian is recommended to neutralize the pre-existing astigmatism.[15] In the present study, MSICS was performed in cataract patients with 1.00–3.00 D of pre-existing corneal astigmatism, and the effect of increasing incision size placed at the steeper meridian was determined.

Because the ATR shift in astigmatism occurs with age, most of the senile cataract patients are expected to have a flatter vertical meridian and would require a temporal approach.[1,2,16] The temporal MSICS is technically more challenging than superior approach because of the lack of forehead support and increased risk of intraoperative iris prolapse caused by suboptimal valvular effect of the sclero-corneal tunnel in the thin temporal sclera. Also, a larger wound size required for a similar nuclear grade because of the elliptical shape of cornea and an exposed wound increases predisposition to endophthalmitis.[17] We observed a pre-existing ATR astigmatism in 67.5% (27 of 40) eyes for which a temporal MSICS was performed. However, no intra or postoperative complications were noted, as all the surgeries were performed by an experienced surgeon.

Superior incisions are reported to produce 48.28% higher SIA than temporal incisions. This has been attributed to the drag produced by gravity and eye-lid blinking movements and greater proximity to the visual axis.[18] The nasal incisions cause greater impact on the corneal curvature as the optical center is more nasal and inferior to the geometric center.[6,16]

Gokhale *et al*.[19] used a 6.0 mm frown incision placed 1.5 mm from limbus and reported an SIA of 1.36 ± 1.03 D, 0.51 ± 0.49 D, and 0.40 ± 0.40 D with superior, supero-temporal, and temporal incisions, respectively. In another study, SIA of 1.45 ± 0.74 D and 0.75 ± 0.41 D was reported with superior and temporal 6.5 mm frown incisions, respectively.[18] Anders *et al*.[20] observed an SIA of 0.65 ± 0.23 D, 0.86 ± 0.53 D, 0.97 ± 0.41 D, and 1.33 ± 0.63 D, with temporal scleral, temporal limbal, superior scleral, and superior limbal incisions, respectively, at 8 months following a 7.0-mm trapezoidal incision. In our study, although the overall SIA was higher in the superior in comparison to the temporal approach, the difference was statistically insignificant possibly because of a small sample size.

Various modifications in the shape of the external scleral incision have been suggested to reduce the SIA.[3,21] The transposition of the ends of the scleral incision away from the limbus improves the wound stability by reducing the wound sag and corneal distortion.[22] Therefore, the U-shape and V-shape/Chevron incision show lower SIA than the straight incisions.[3,5] Akura *et al*.[23] compared the effect of

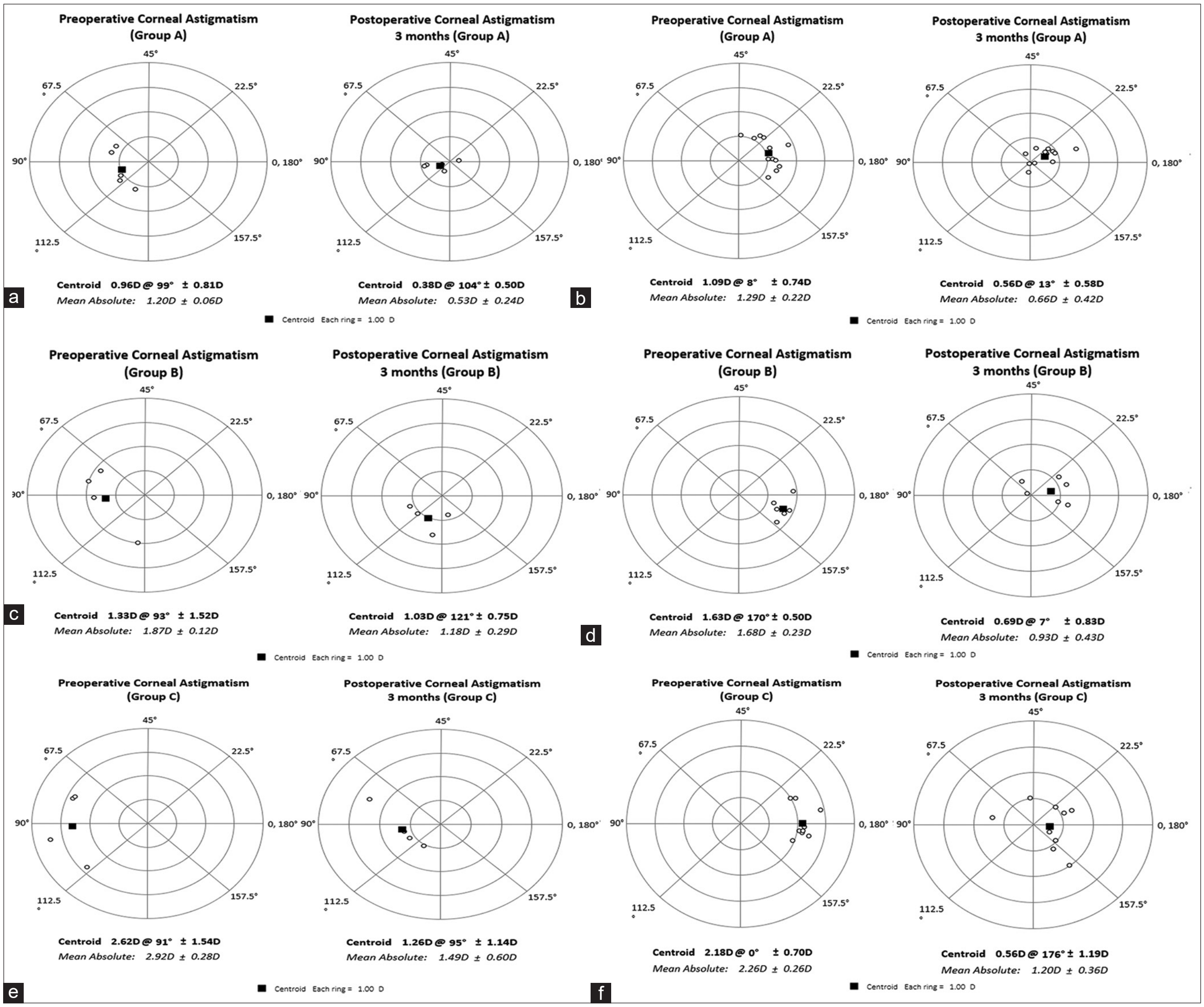

Figure 2: Double angle plots and centroid for pre-operative and 3 months post-surgery corneal astigmatism. Each ring denotes 1 D of astigmatism. The centroid (solid circle) is the arithmetic mean of astigmatism of individual cases (empty circle). (a) group A superior incision (b) group A temporal incision (c) group B superior incision (d) group B temporal incision (e) group C superior incision (f) group C temporal incision

arcuate versus frown incision of size 6.0–7.0 mm, placed at the steepest axis (superior or temporal) during MSICS. They noted mean SIA of 1.03 D, 0.79 D, 0.64 D, and 0.52 D with superior arcuate, temporal arcuate, superior frown, and temporal frown incisions, respectively, at 6 months follow-up, with a reduction in astigmatism in 98% of the study cases. We used straight incision in all patients to increase the SIA.

The optimal depth recommended for the sclero-corneal tunnel is 30–50%. In a recent study, SIA was found to be higher in superficial incisions (tunnel depth <400 microns) than deeper incisions (at ≥400 microns depth).[24] On the contrary, no difference was reported in SIA in 300 and 600 microns depth 7-mm trapezoidal incisions.[20] In our study, the depth of the incision was <400 microns in all the cases.

Corneal SIA was found to be directly proportional to the cube of the length of incision.[25] Burgansky *et al*.[26] showed a progressive increase in SIA with enlargement of external wound, the SIA being 0.60 ± 0.30 D, 0.75 ± 0.67 D, and 1.36 ± 0.77 D for 6.0-, 6.5-, and 7.0-mm incision, respectively. In our series, the SIA was 0.85 ± 0.28 D with 6.0 mm, 1.32 ± 0.65 D with 6.5 mm, and 1.91 ± 0.69 D with 7-mm incision. The highest correction achieved was 1.13 D with 6.00-mm incision, 1.97 D with 6.5 mm, and 2.60 D with 7.0-mm incision.

The DAP in group A, B, and C showed clustering of cases in the postoperative plots implying a high predictive value [Fig. 2]. A progressively greater shift of the centroid towards the centre of the DAP was observed with a larger incision size. For the superior incision group, reduction in the magnitude of steepest astigmatism in the vertical meridian was seen as clustering around 90° axis. In the temporal incision group, the reduction in astigmatism along the steepest horizontal meridian was illustrated by clustering around 0° and 180° meridians.

The limitations of the study were a small sample size and lack of comparison with smile incision that was likely to increase SIA. Because the distance from the central cornea can affect the SIA,[6] inclusion of corneal diameters was desirable.

Conclusion

In conclusion, customization of on-axis external incision size can be used to manage pre-existing corneal astigmatism of less than 3.00 D using both temporal and superior incisions effectively. Given the majority of the senile cataract patients presenting with ATR, use of temporal approach should be emphasized in cataract surgery training programmes.

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Conflicts of interest

There are no conflicts of interest.

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